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(ITU-T SG8)

Coding of Still Pictures

JBIG	**JPEG**
Joint bi-level Image Experts Group	Joint Photographic Experts Group

TITLE:	Report on Core Experiment CodEff02 (Rochester), “7-tap/5-tap Filter Bank Option”
SOURCE :	Chris Brislawn Los Alamos National Lab, USNB
PROJECT :	JPEG 2000
STATUS :	Report
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Core Experiment Description/Results Summary on VM 7.2

Experiment Name: 7-tap/5-tap Filter Bank Option (Part 2)

Sub-Group: _Coding Efficiency__ Number: __CE02 (Rochester)

Description:

Core experiment **partners**	Los Alamos National Lab-USA, Motorola Australia
Core experiment **objective**	Design and characterize performance of proposed 7/5 filter bank as a Part 2 option.
JPEG 2000 **Requirement** Focus	Expand user options for complexity-vs.-performance tradeoffs.
What will **change** fro[m] Verification Model 7.[0]	Additional filter bank option.
Key **Benefit** of chang[e]	Intermediate complexity and performance as compared to 9/7 and 5/3 filter banks in Part 1.
Related Experiments	
Expected Memory Decrease/increase	no anticipated changes
Expected Complexity Decrease/increase	Intermediate DWT complexity as compared to 9/7 and 5/3 filter bank[s] in Part 1.
Other expected result[s]	

Core experiment detai[led] description	Produce a 7-tap/5-tap filter bank optimized for JPEG-2000 applications using recently developed numerical design techniques. Characterize complexity, coding gain, and rate-distortion performanc[e] in comparison to the 9/7 and 5/3 filter banks in baseline (Part 1).

Results:

VM Mode Used in Experiment	VM 7.2, 5-octave (Mallat) decomposition, decoded at rates of 0.0625, 0.125, 0.25, 0.5, 0.75, 1.0 bpp. Results taken on 12 grayscale JPEG test images.

What has **changed** from Verification Model 7 (provide level of integration)	no changes to VM except provision of a new filter kernel file

Was this experiment **performed** on the VM or in a testbed	VM 7.2

Key **Benefit** of change	We have demonstrated that the proposed 7-5 filter bank is a viable alternative with characteristics intermediate to those of the irreversible 5-3 and 9-7 filter banks.
Key **Cost** of change	Typing up an additional example of an optional filter bank in Part 2 Annex F.4.

Key **findings**	This 7-5 filter bank consistently produces SNR results in-between the SNR's generated using the 5-3 and 9-7 filter banks. It improves on the version presented in our interim report (Arles) by having improved low-rate performance relative to the irreversible 5-3. Moreover, it represents globally optimal performance in the 7-5 filter bank category.

Recommendation:

We recommend including this filter bank in Part 2 Annex F.4 as an example of an optional JPEG-2000 filter bank and adding its kernel file to the VM distribution.

1 Introduction

The intent of this report is to describe the quantitative performance of a new 7-tap/5-tap linear phase filter bank designed by numerical optimization methods. This report concludes the partial results presented in Arles on Core Experiment CodEff_07 (wg1n1761). The motivation for this work is to produce an alternative to the 9-7 and 5-3 filter banks (the baseline filter banks in Part 1), with intermediate coding performance and intermediate complexity.

2 Experimental Setup

The new filter bank was generated by a numerical optimization procedure and tested for image-coding performance on VM 7.2 using JPEG test images. The exact test conditions were as follows.

2.1 Filter bank design

The 7-5 filter bank was designed using a group-theoretic cascade-form polyphase matrix factorization developed by the author and O. Treiber[1]. The factorization was constrained to ensure that both the analysis and synthesis wavelets have two vanishing moments. In the 7-5 category this leaves a single unused degree of freedom, α_3, which is then optimized for coding performance. (It turns out that α_3 is equal to the multiplier weight in the first analysis lifting step, which is denoted α.) In wg1n1761, α_3 was used to optimize an analytic model of theoretical coding gain for highly correlated AR(1) processes (correlation coefficient = 0.95) with 5 levels of subband decomposition. In the present report, we present results based on global optimization of empirical rate-distortion measurements using VM 7.2 on JPEG test images.

The AR(1, 0.95) coding gain and Hoelder regularity landscapes for the 7-5 category are plotted with respect to α_3 in Figure 1. In all cases we are using the long (7-tap) lowpass filter for analysis. The filter bank described in wg1n1761 was defined by the parameter value $\alpha_3 = 0.05$; the filter bank advocated in this report is defined by the parameter value $\alpha_3 = 0.08$. The value $\alpha_3 = 0$ corresponds to the natural embedding of the 5-3 LeGall-Tabatabai filter bank[2] (the irreversible version of the 5-3 filter bank from Part 1) into the 7-5 category, so our 7-5 filter banks can be regarded as perturbations of the 5-3 LeGall-Tabatabai filter bank in a higher-dimensional parameter space. See Figure 2, Figure 3, and Figure 4 for a comparison of the LeGall-Tabatabai filter bank and the 7-5 ($\alpha_3 = 0.05$ and $\alpha_3 = 0.08$) filter banks.

[1] C. Brislawn and O. Treiber, "Lattice Structures for Parametric Design of Odd-Length Linear Phase Filter Banks and Regular Wavelets," in preparation.
[2] D. LeGall and A. Tabatabai, "Subband coding of digital images using symmetric short kernel filters and arithmetic coding techniques," Proc. IEEE ICASSP-88.

As one can see from the figures, the $\alpha_3 = 0.08$ filter bank has a slightly less-smooth synthesis filter bank but smoother analysis filter bank and less lowpass analysis passband ripple than the $\alpha_3 = 0.05$ filter bank. The reason for recommending this change from wg1n1761 will be explained in the next section. Both filter banks have 2 vanishing moments, rational impulse responses and lifting parameters, and DC gains of unity.

The impulse responses for the $\alpha_3 = 0.08$ filter bank are in Table 1; we wish to thank Dr. Tony Warnock of LANL for deriving the rational expressions for the impulse response taps via continued-fraction expansions. The rational lifting parameters for the $\alpha_3 = 0.08$ filter bank are in Table 2, followed by the text of a VM kernel file. Note that the VM syntax requires an initial lifting step of 0 for this filter length, and the software implementation (VM 7.2) requires that it be a length-2 weight sequence!!

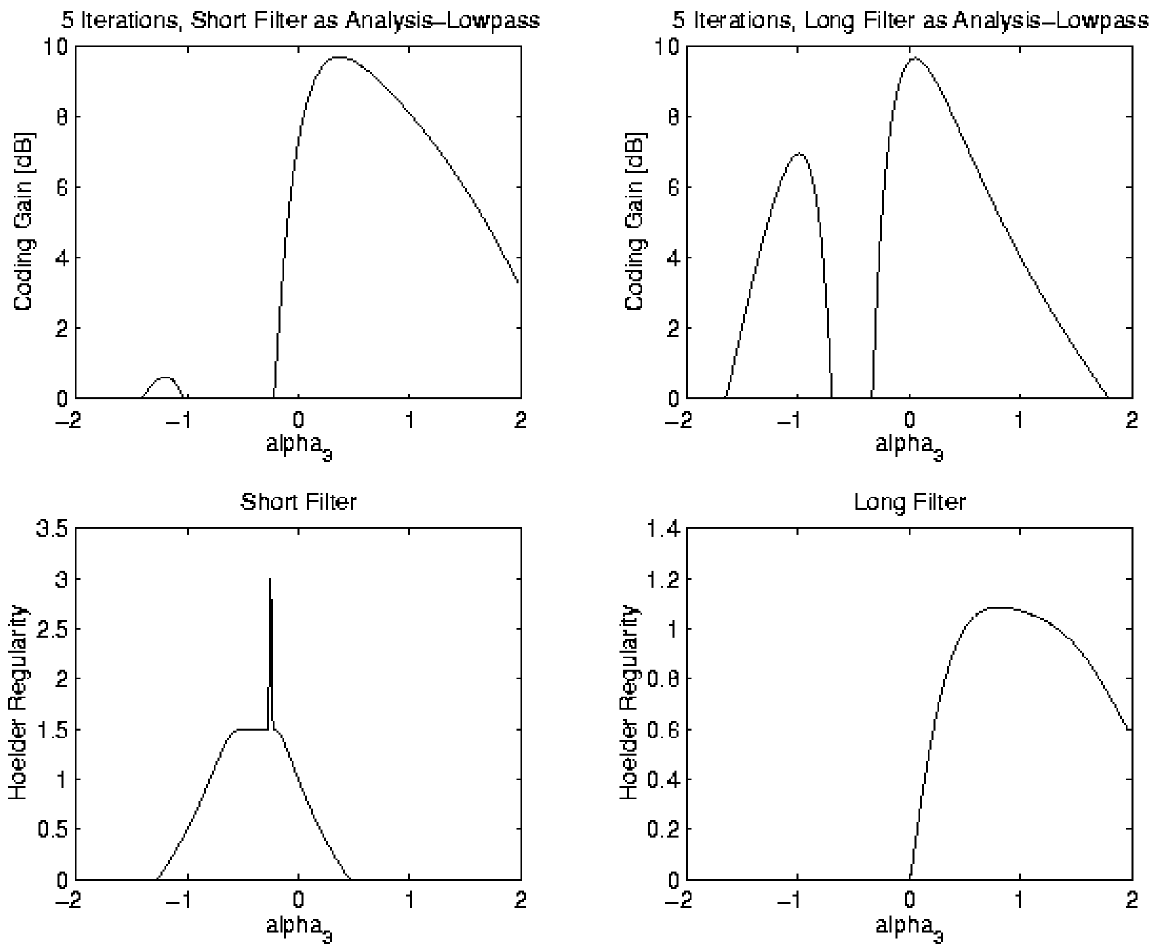

Figure 1. AR(1, 0.95) coding gain and regularity landscapes for 7-5 filter banks.

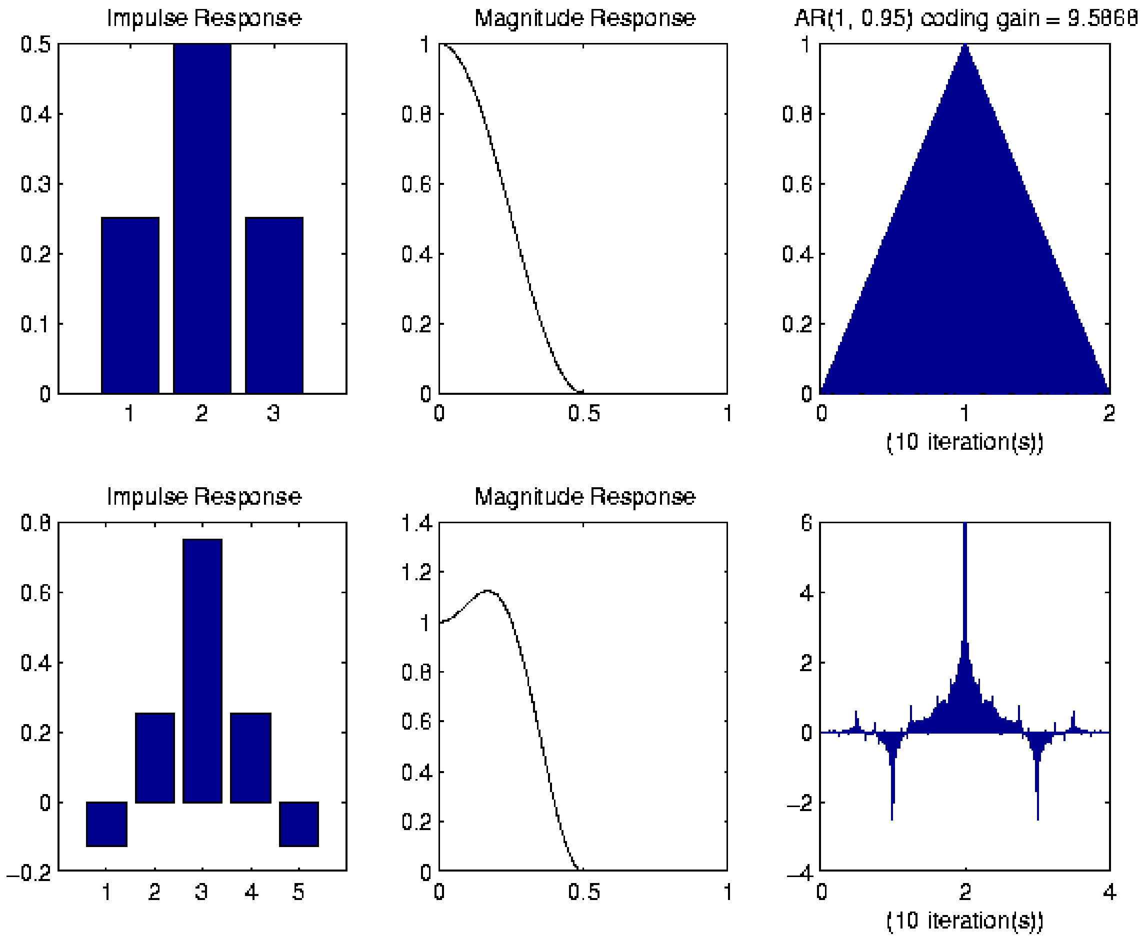

Figure 2. LeGall-Tabatabai 5-3 lowpass filters and corresponding scaling functions.

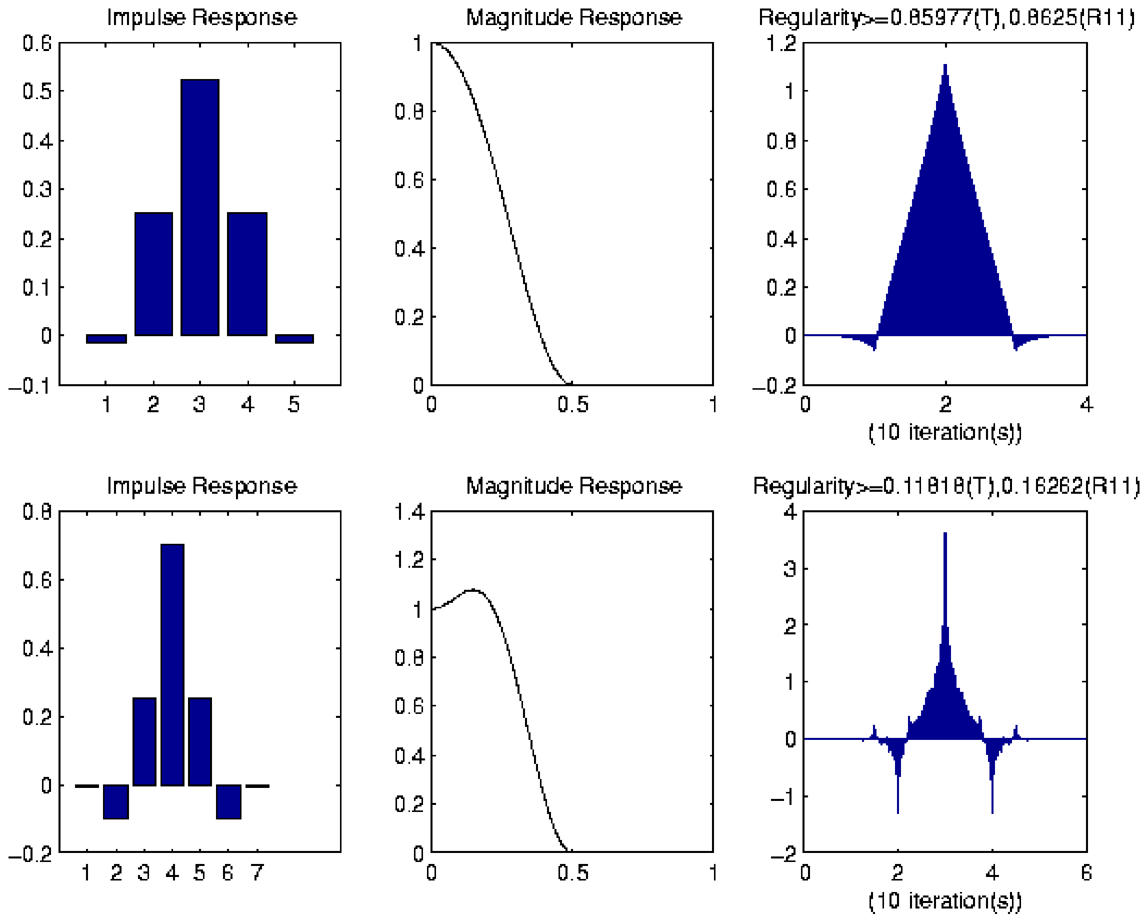

Figure 3. Brislawn-Treiber 7-5 filter bank from wg1n1761, parameter $\alpha_3 = 0.05$.

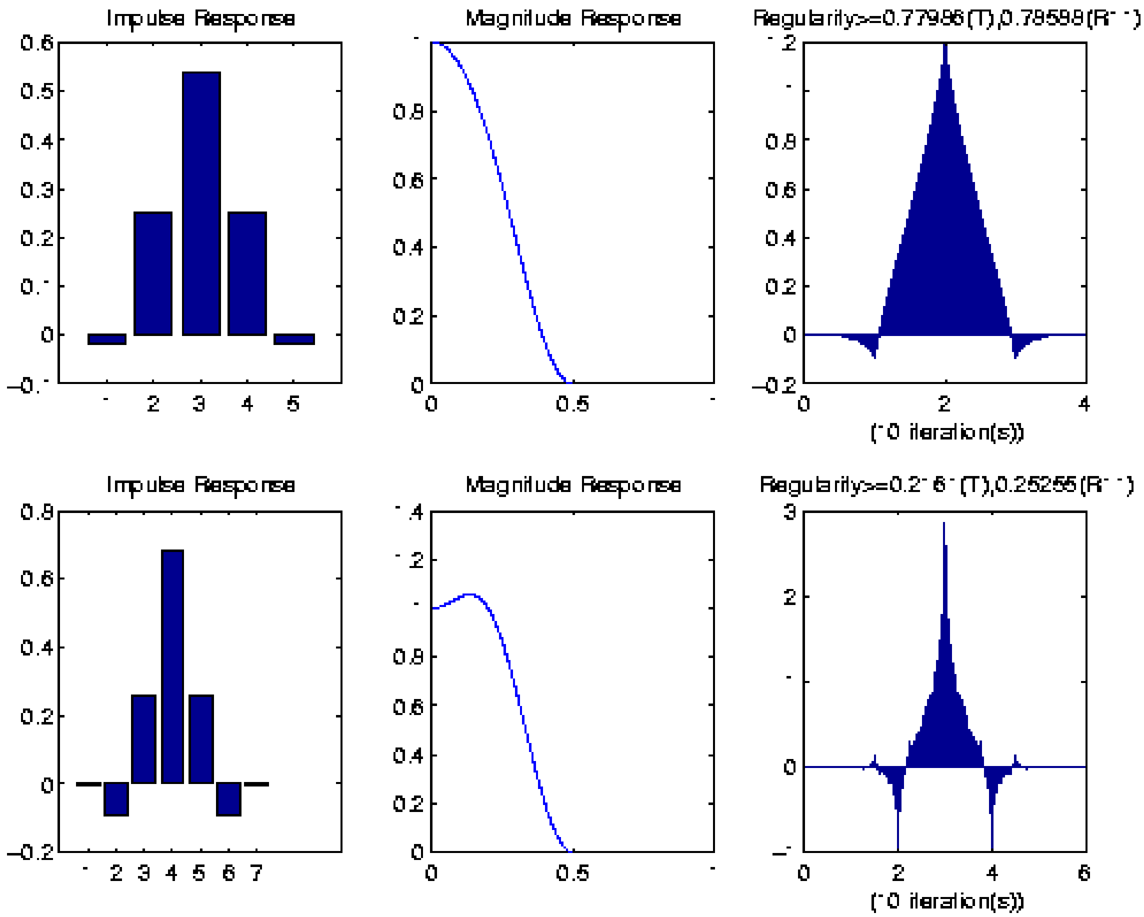

Figure 4. Brislawn-Treiber recommended 7-5 filter bank, parameter $\alpha_3 = 0.08$.

Table 1. Impulse responses of the recommended 7-5 lowpass filters, $\alpha_3 = 0.08$.

n	$h_0(n)$ *(analysis)*	$f_0(n)$ *(synthesis)*
0	79/116	27/50
±1	373/1450	1/4
±2	-21/232	-1/50
±3	-21/2900	

Table 2. Lifting parameters for the recommended 7-5 filter bank, $\alpha_3 = 0.08$.

parameter	*value*
α	2/25
β	-175/406
γ	609/2500
K	25/29

Text of the VM kernel file for the recommended 7-5 filter bank:

```
2 2 2 2    # This is the 7-5 filter bank with alpha_3 = 0.08
0             0  # it is necessary to start with a length-2 null lifting step in VM 7.2
0.08                    0.08
-0. 4310344828      -0. 4310344828
0. 2436                 0. 2436
```

2.2 Experimental results

In wg1n1761, the rate-distortion performance of the $\alpha_3 = 0.05$ filter bank was evaluated and compared against the performance of the 9-7 and 5-3 filter banks in irreversible implementations with entropy-constrained optimal rate allocation. The lifting parameters for all 3 filter banks were supplied to VM 7.2 using the float_lifting syntax. In that report, we showed that the $\alpha_3 = 0.05$ filter bank consistently performed somewhere inbetween the performance of the 9-7 and irreversible 5-3 filter banks when used to code JPEG test images. The principal shortcomings of wg1n1761 were that (1) the choice of $\alpha_3 = 0.05$ was based on optimization for AR(1, 0.95) sources rather than on optimizing actual performance on continuous-tone images, and (2) testing on actual images indicated that the performance advantage of the $\alpha_3 = 0.05$ filter bank deteriorated at extremely low bit rates (below 0.25 bpp). Addressing these shortcomings has led us to recommend the $\alpha_3 = 0.08$ filter bank as an improvement over the $\alpha_3 = 0.05$ filter bank.

For this report, we computed SNR landscapes for a range of α_3 values at rates of 1.0, 0.75, 0.5, 0.25, 0.125, and 0.0625 bpp. SNR figures were averaged over a dozen cropped (512 x 400) JPEG test images, selected for diversity of image content. It was necessary to use cropped images because of the considerable computational load these experiments entailed. Images were compressed to 4.0 bpp with –Clayers set at the desired decoding entropies. The command lines used for irreversible coding were:

```
% vm_compress  -i $image_root[$i].pgm  -o $image_root[$i].jp2  -rate 4.0  -Fdir $local_path  -Fkernels $k
-Clayers 0.0625 0.125 0.25 0.5 0.75 1.0

% vm_expand  -i $image_root[$i].jp2  -o $image_root[$i].recon.pgm  -trunc $rate[$r]
```

SNR averages over the 12 images were made for 19 filter banks parameterized by α_3 values ranging from –0.24 to 0.48 in increments of 0.04; the resulting curves are shown in Figure 5. This interval contains the global maximum for coding performance. The value $\alpha_3 = 0$ representing the natural 7-5 embedding of the irreversible 5-3 filter bank, and it can be seen from this plot that some improvement is possible at values $\alpha_3 > 0$.

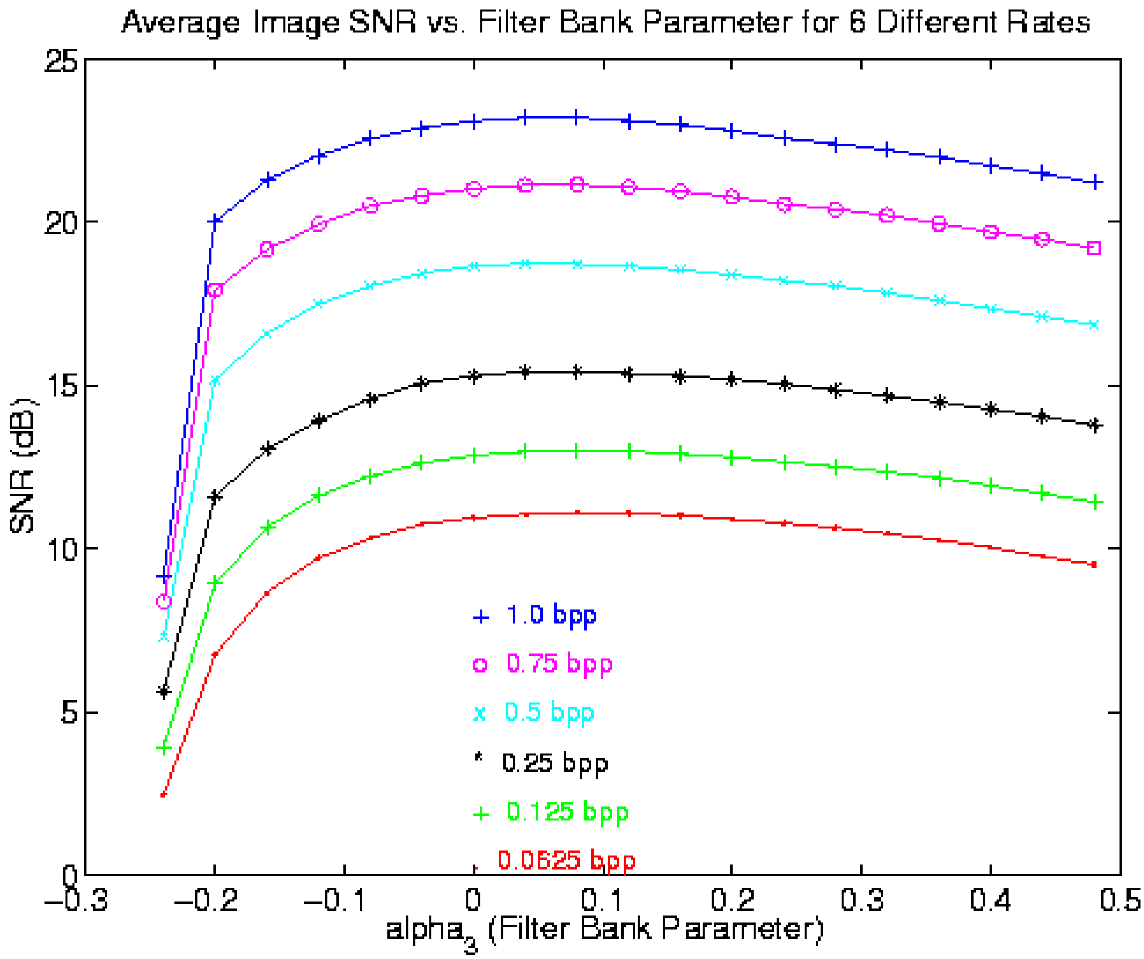

Figure 5. Image SNR landscape for 7-5 filter banks.

To localize the global maximum for image coding performance in the 7-5 category, more tests were made for 21 filter banks from $\alpha_3 = 0$ to $\alpha_3 = 0.2$ in increments of 0.01. The curve for 1.0 bpp is seen in Figure 6. Performance improves over $\alpha_3 = 0$ by about 0.1 dB SNR for α_3 between 0.03 and 0.09. This characteristic holds down to about 0.25 bpp, but the curve changes below 0.25 bpp. As seen in Figure 7 and Figure 8, at low rates the peak performance shifts to slightly higher values of α_3. The peak for 0.0625 bpp is at $\alpha_3 = 0.08$, with an improvement of 0.15 dB SNR over the 5-3 filter bank. Since this is near the upper limit of the performance peak at 1.0 bpp, we have settled on that parameter value as providing near-optimal performance at all rates from 1.0 down to 0.0625 bpp. In particular, as can be seen in Figure 8, $\alpha_3 = 0.08$ represents an improvement of about 0.05 dB over the performance of $\alpha_3 = 0.05$ at 0.0625 bpp, fulfilling our goal of bettering the low-rate performance of the recommended 7-5 filter bank.

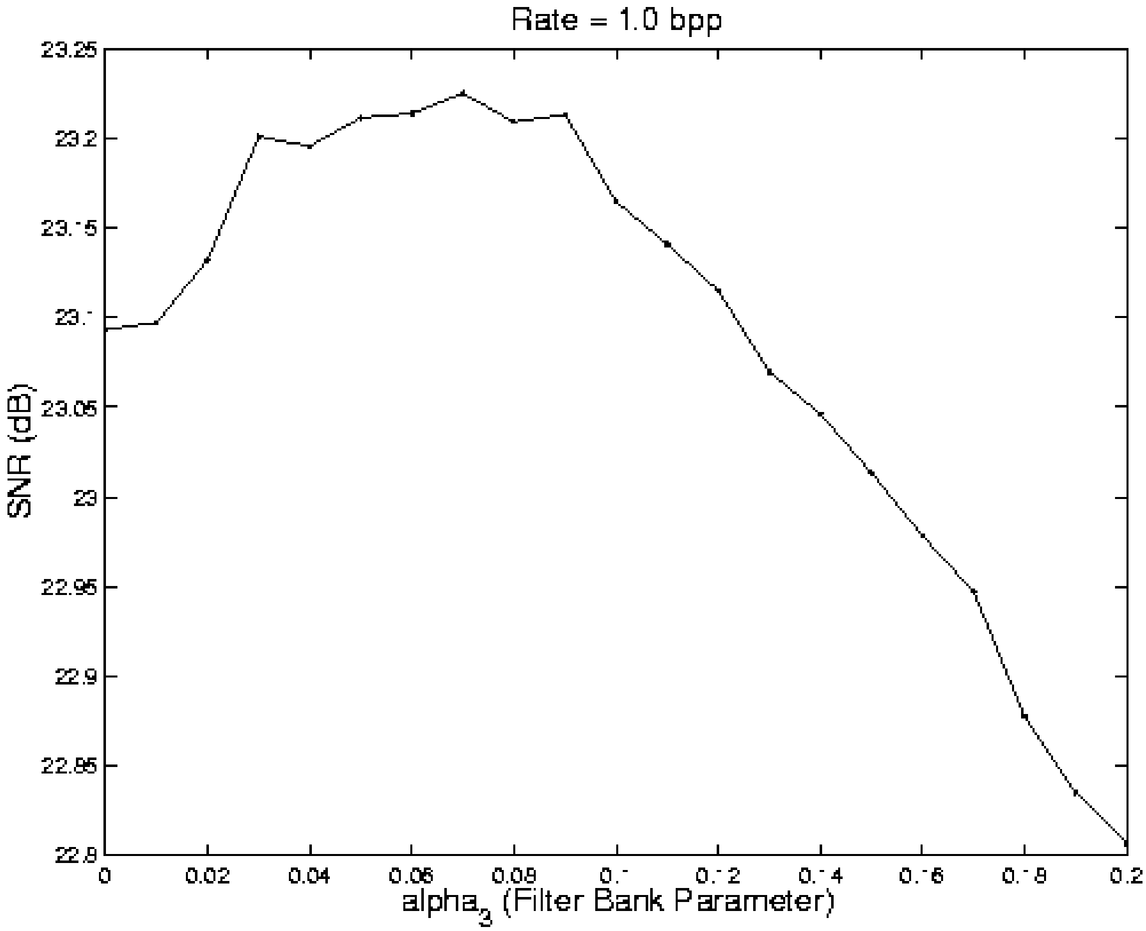

Figure 6. SNR performance of 7-5 filter banks at 1.0 bpp.

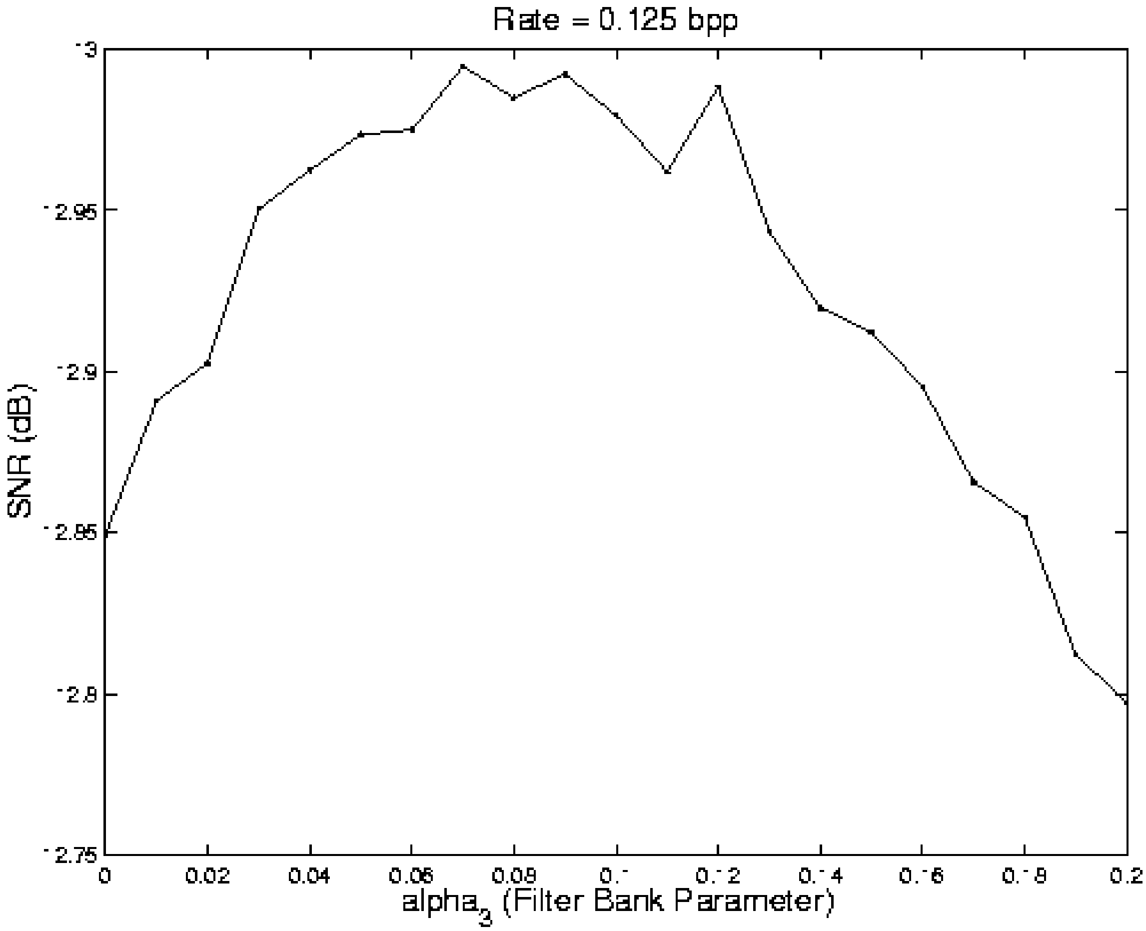

Figure 7. SNR performance of 7-5 filter banks at 0.125 bpp.

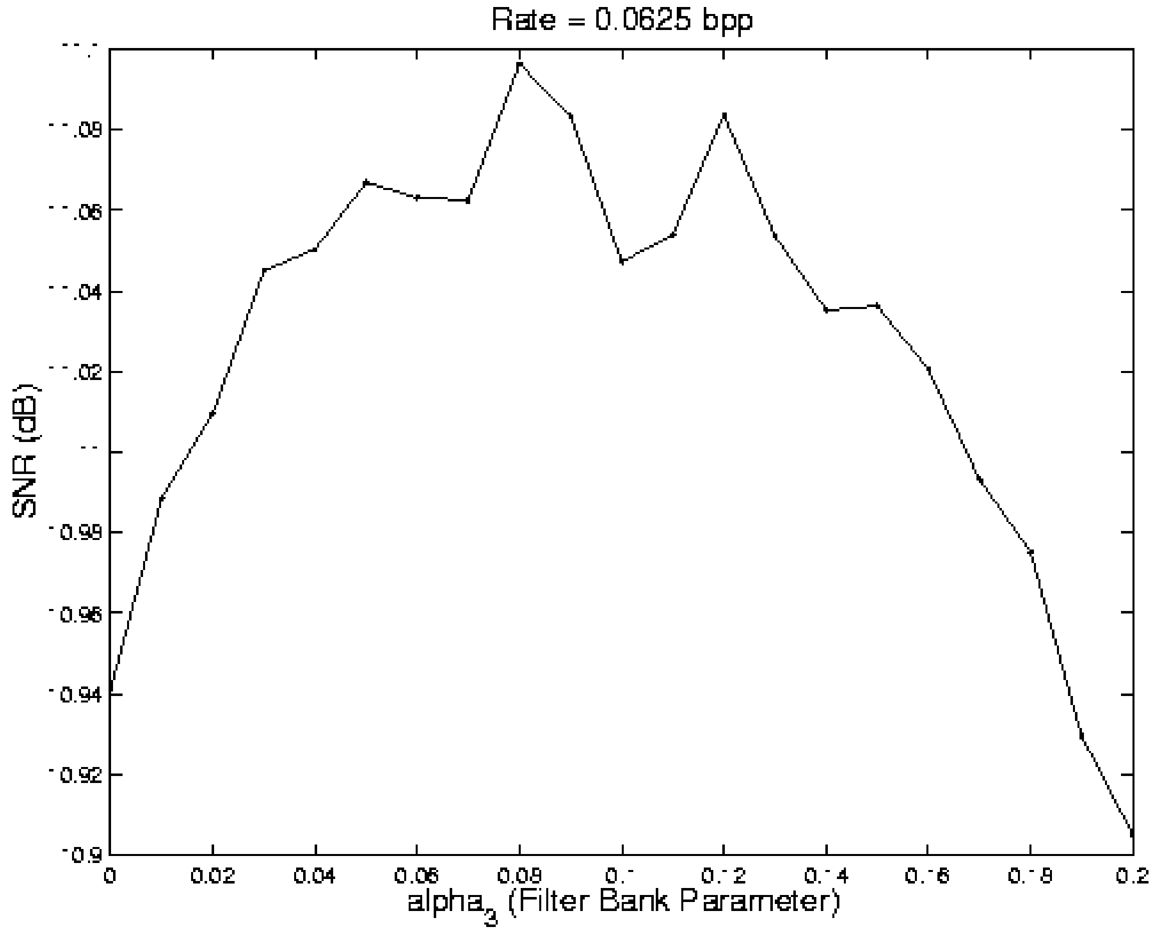

Figure 8. SNR performance of 7-5 filter banks at 0.0625 bpp.

3 Summary

In this and our previous report (wg1n1761), we have shown that both the empirical image-coding performance and the implementation complexity of the proposed ($\alpha_3 = 0.08$) filter bank lie midway between the corresponding characteristics of the irreversible 5-3 and 9-7 filter banks. Moreover, we have shown that the performance of the $\alpha_3 = 0.08$ filter bank is globally optimal in the 7-5 category for image coding at rates of 1.0 down to 0.0625 bpp. This makes the proposed 7-5 filter bank a viable intermediate alternative to the irreversible 5-3 and 9-7 filter banks.

4 Recommendation

We recommend:

1. Including the $\alpha_3 = 0.08$ filter bank in Part 2 Annex F.4 as an example of an optional JPEG-2000 filter bank, and
2. Adding its kernel file to the VM distribution.